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The Rainbow and the worm
Establishing a new physics of life

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What is life? Many have asked this question, and no definitive answer is yet widely accepted. Is life something truly distinct from non-living stuff, as many dualists have suggested for millennia? Is there an élan vital that distinguishes living from dead stuff? Or is life about certain types of organization, metabolism, reproduction, goal-oriented behavior? None of these answers have yet won the debate, though dualistic ideas have (rightfully) become far less prevalent. There is, however, an intriguing new set of ideas that have been developed by Mae-Wan Ho, a biophysicist and science activist (as she calls herself) based in London. Ho's basic assertion is that life exists on a spectrum and is at its root organized, quantum coherent energy. Ho's work attempts to bridge the gap between physics and biology by recognizing that there is no real gap at all—just a gap in current methods and habits of thinking. In researching and developing my own views on the nature of life and on evolution, I've found Ho both a kindred spirit on many issues and also a goad to further research and thought. The increased interest in quantum biology in recent years is perhaps an indication that the ideas that Ho has been developing for some decades are catching on. One of Ho's key ideas is that quantum physics does indeed have macro-level effects, and life itself is in many ways defined by its ability to bootstrap quantum communication to the macro level. Ho is strongly inspired by Alfred North Whitehead, the British philosopher, mathematician and physicist who developed an extraordinarily detailed and far-reaching vision of nature that is quite different than the materialist views that hold sway in many quarters today. I've also been inspired by Whitehead and it is intriguing as I make my way through readings in biology, physics and philosophy to see how many thinkers have been influenced by Whitehead. I highly recommend Ho's books to anyone interested in cutting-edge biology or biophysics, or anyone interested in related philosophical issues. Ho is a brilliant researcher and synthesizer who I feel will be lauded widely as her ideas achieve broader acceptance in coming decades. She can tend toward the mystical and artistic at times in her work, which I find intriguing and effective in helping to create a broader understanding of nature and our place in it, though this tendency is unusual among most working scientists. It can be off-putting to some who are not used to this type of presentation—I urge those readers who are not used to it to push through. I had the pleasure of interviewing Mae-Wan via email about her books, *The Rainbow and the Worm: The Physics of Organisms* (now in its third edition) and *Living Rainbow H_2O*, her newest work about the startling properties of water and its relation to life as we know it.

How did you decide to focus on the "physics of organisms" as a career?

I've dreamt of understanding life ever since hearing of Szent-Gyorgyi's remark that "life is interposed between two energy levels of an electron" as a biology undergraduate in Hong Kong University. I did a Ph.D in biochemistry, but biochemistry did not and still does not address the question What is Life? that quantum physicist Erwin Schrödinger asked in his 1944 book of that title. Szent-Gyorgyi is the father of biochemistry, and as I got deeper into my research, I realized that the two scientists were way, way ahead of their time, and got a lot of things right.

What is your personal background and primary inspiration for your work?

I grew up in Hong Kong when the 'bamboo curtain' was in place. The then British colony was a cultural desert with Coca Cola adverts and Hollywood movies filling the vacuum. My parents, aunts and uncles were typical of well-to-do middleclass Hong Kong Chinese caught up in the drive to be "modern" ("more dung" in Cantonese pronunciation), while my grandparents' generation clung on to the old ways for better or for worse but without much conviction. China, after all, lost the war to the West, to modernism, and lost very badly indeed. To this day, the humiliation suffered at the hands of Western foreigners (and the Japanese) is still palpable among the older Chinese, and with that, the fear of being backward, and not keeping up with modernity.

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I had six grandmothers on my mother's side and one on my father's side. My biological grandmother was the 5th grandmother, a concubine gifted to my grandfather by his friend who had bought her as a maid. She was my lifeline. A devout Buddhist, she was beneficence incarnated. She gave and taught me unconditional love, and simultaneously freedom and spontaneity. Fifth Grandmother was the yardstick, the golden standard against which all else was to be measured. I am not a Buddhist, but discovered instead that I am thoroughly a Taoist by nature, which is strange, as I was never, ever trained in Taoism. I think it must be part of a collective unconscious, or I would now say, the quantum memory of millennia written into the vacuum field that I have access to. My physics of organisms presented in *The Rainbow and the Worm* was strongly influenced by this quantum memory. (The 'physics of organisms' is to be distinguished from 'biophysics', which is about more mundane things like X-ray diffraction and other physical instrumentation applied to biology, so I am not a traditional biophysicist.) I found my way back to the holistic knowledge of my own culture via contemporary Western physics, which convinces me that I was rediscovering something universal.

What are the key points of your books *The Rainbow and the Worm: The Physics of Organisms* and *Living Rainbow H_2O*?
The Rainbow and the Worm set out to answer the question, what is life?, that Schrödinger asked. Most people thought he provided the answer by postulating DNA as the genetic material. That was only part of the answer. The other part he suggested was quantum coherence, a state of being whole that involves molecules acting in perfectly correlated ways, and a special thermodynamics of life, which he referred to a "negentropy", or "negative entropy". Following these leads, I extended conventional quantum physics and non-equilibrium thermodynamics to provide the tentative answer, drawing on the work especially of Herbert Froehlich, Fritz Albert Popp and Kenneth Denbigh, and empirical evidence from the scientific literature and my own research.

Life, in the ideal, is a domain that captures and stores energy and mobilizes it quantum coherently in perfectly coupled cycles that generate no entropy. This is a very compact statement, but it took years and several editions of the book to get to this conclusion, and the implications are rich, which is why it took the entire book to develop. They range from the physics of sustainable systems to the naturalistic ethics universally adopted by all cultures, that of doing no harm to others. In a quantum coherent universe, all beings are both localized as particle/solid objects and delocalized as quantum wave functions spread ultimately throughout the universe. Hence all beings are mutually entangled and mutually constitutive. Thus, harming others effectively harms ourselves, and the best way to benefit oneself may be to benefit others.

Living Rainbow H_2O is a sequel to *The Rainbow and the Worm*, concentrating on the latest findings in the quantum physics and chemistry of the liquid crystalline water in the living matrix that enables noiseless, rapid intercommunication to take place, as required of quantum coherent system. Water also provides the electricity that energizes and animates life. That is why water is "the means, medium and message of life." It is the "rainbow within" because its liquid crystalline state enables molecules to line up and move coherently together, creating interference colours when viewed under the polarizing microscope, which are the stuff of rainbows. A whole new cell biology and biology of life is emerging, based on water, that has been completely left out in the reductionist and overly mechanistic biology of the mainstream

Why have so few people taken up where Erwin Schrödinger, the Nobel Prize-winning physicist and author of the 1944 classic book *What Is Life?*, left off in terms of trying to mesh physics with biology?
Lack of courage in addressing big questions or to disagree with the mainstream, lack of imagination, lack of funding, too much concentration on molecular nuts and bolts, domination of reductionist biology, too much specialization and lack of interdisciplinary training, lack of appreciation of the beauty of nature. In my opinion, to really understand nature, one needs to be both a romantic poet and artist at heart.

One feature of *The Rainbow and the Worm* (*RAW* from now on) that struck me is the common practice in biology of destroying organisms in order to study them and how many of your insights about life arose from examining live organisms with tools that include creating images of the "rainbow worm" of your title. How do your non-invasive techniques compare to the invasive and generally lethal techniques historically used in biology?
Non-destructive, minimally invasive observation is the key to really knowing and understanding organisms, i.e., with the utmost sensitivity in all of one's senses including one's appreciation of beauty and love, so that the known is most itself as the knower is most herself. That is also the highest order quantum coherent state of being one with the known. Discovering that truth made me realize the violence we do, not only to nature but most of all to ourselves. Through traditional invasive techniques, we lose the sensitivity that makes us most alive, and most ready to be inspired.

Perhaps your most important definition of life offered in *RAW* (of a few complementary definitions that you offer) is this: "The organism is, in the ideal, a quantum superposition of coherent activities over all space-times..." Can you explain briefly how you came to this conclusion and what it adds to the thoughts offered by Schrödinger in his 1944 book?
Many people following Schrödinger have proposed that the organism is quantum coherent, prominent among them, Fritz Albert Popp, Emilio Del Giudice and Fröhlich, all of whom I learned a great deal from, though not always what they intended to teach me. However, *RAW* was the only book that connected and reinterpreted conventional biochemistry and physiology, physics, chemistry, and mathematics, as well as everyday experience, with quantum coherence. Living activities span a wide range of space and time scales. The nearest analogy to the quantum coherence of a living system is a laser that becomes coherent simultaneously in more than one frequency, and all the frequencies are coupled together.

You offer a number of arguments for viewing life as essentially quantum coherent systems, based primarily on the degree to which the various parts of organisms are able to work autonomously but still remain highly coordinated—and you analogize the functioning of organisms to highly intricate jazz ensembles playing over a range of 74 octaves. I certainly like the poetry of this description, but I must admit that I'm not yet convinced by your arguments that quantum coherence must be at play at the macro level or intermediate level in organisms. Aren't there other possible forces/mechanisms/information pathways at play that don't have to involve quantum coherence?

There aren't really other possible forces/mechanisms/information pathways that don't have to involve quantum coherence when you take note of the liquid crystalline (condensed state) of the living matrix (both intracellular and extracellular). I am not saying organisms are perfectly quantum coherent, i.e., coherent to nth order where n is a very large number approaching infinity. If that were the case, they would never age and never die. In other words, there are degrees of quantum coherence, and the higher the order, the less quickly the organism ages. *RAW* is a very radical book; it contains other proposals—apart from the main ones regarding quantum coherent organisms and circular thermodynamics—especially about space and time. Notably, I suggested that both space and time are created by organic processes; time's arrow arising from entropy generated by the incoherency of process. Hence an individual's biological time can be very different from external mechanical time. People who live more coherently may age more slowly.

On a similar note, you argue that quantum coherence allows instantaneous transfer of information, and thus the development of highly coordinated organisms across many scales of space and time. Yet quantum coherence doesn't have to be instantaneous in nature. Salart, et al., a Swiss team studying quantum entanglement, found in 2008 that entanglement operates at speeds at least 10,000 times the speed of light (which doesn't rule out instantaneity, of course). Does it matter to your theories about biophysics whether entanglement operates instantaneously or "merely" at many orders of magnitude faster than the speed of light?

Again, quantum coherence can exist to different degrees (order), my zero-entropy (perfectly quantum coherent) theory of the organism is an ideal that can be achieved perhaps once or maybe several times in a life-time, in an especially inspired state, or in an emergency. So instantaneous transfer of information is similarly an ideal towards which the living system approaches (asymptotically). However, *RAW* also proposed, following quantum physicist Wolfgang Schommers, that there is a time-energy uncertainty relationship in parallel with the usual Heisenberg position-momentum uncertainty, that involves real uncertainty in time, so much so that time can go backwards.

Staying with the issue of instantaneity versus merely faster than light transfer of information, isn't this a pretty crucial distinction for both physics and biophysics? Can instantaneity make sense logically? It seems that if we have distinctions in the physical world, as we do, with matter/energy existing in an "extensive continuum" (to use Whitehead's phrase), that instantaneous transfer of information or causation may be logically impossible.

From the observer point of view, there is no distinction between traveling faster than light and instantaneity. The whole of quantum encryption and quantum information transfer, and even teleportation, depends on instantaneity. These experiments have already been done in the real world. I am among those scientists that do not believe there is a distinction between the classical world and the quantum world, as quantum effects have now been demonstrated at the macroscopic level, say, in superconductivity, and also quantum interference and wave particle duality for particles as big as viruses. We live in a quantum world, and we only observe classical effects because we insist on applying mechanical and mechanistic methods to relate to it. As someone said, if your only tool is a hammer, then everything looks like a nail.

Whitehead is indeed right, that we cannot understand the physical world except from the point of view of an organism. The important point to stress is that organisms are macroscopic quantum objects with a macroscopic wave function that evolves as we entangle other quantum beings in our environment. That is why he said something like: each "actual entity" has reference to every other "actual entity," and each interval of time has reference to every other interval of time. There is ultimately a universal simultaneity in which no space-time separation exists, in a state of complete quantum coherence. Some of us may reach this state via a religious or mystical experience. Others like me touch this sublime state during an intense aesthetic experience (see my article "*In Search of the Sublime*")...

I was fascinated to read in your book about the "liquid crystalline" structure of organisms, with water as the basis for this structure, allowing much faster communication between parts of the organism than electrochemical signaling or other signaling paths allow. Can you briefly describe this feature of your work, including the idea of proton conduction and its role in achieving coherence in organisms?

The liquid crystalline structure of organisms depends essentially on the liquid crystalline water that aligns itself along the enormous amount of interfaces. It is excited water that is easily split by infrared photons absorbed in photosynthesis, into protons, electrons and oxygen. The protons and electrons are positive and negative electricity that basically power molecular machines that, because of the water associated with them, can transfer and transform energy at close to 100% efficiency. The pervasive liquid crystalline water also enables the molecules to act in a highly coordinated way, approaching quantum coherence.

Walter Freeman at UC Berkeley has long argued that his work on rabbit brains demonstrated that certain brain signaling must be faster than is allowed for with neuronal electrochemical signaling. Is the proton conduction structure that pervades animal bodies a likely candidate for this phenomenon or are there likely other pathways at work?

Precisely, only quantum coherent proton and electron transport can account for the instantaneous or faster than light intercommunication that enables distant neurons to fire together, which

is not different from distant muscle fibres acting together in a perfectly coordinated way. At bottom, we, the entire organism —brain and body—are a coherent quantum electrodynamic field that organizes all the genes and molecules. This enables ultimately each individual molecule to intercommunicate with every other, and water holds the key to the intercommunication, as well as memory of the macroscopic wave function that characterizes the individual organism.

Your recent book, *Living Rainbow H_2O*, focuses in on the details of water as crucial to the fine-tuned coherence of organisms. You describe a number of features of water that are in some ways anomalous, including its melting point and many other anomalies. Do you believe the amazing properties of water support some version of the Anthropic Principle or would you suggest some other conclusion?

There is no need to invoke the anthropic principle. That's the refuge of the ignorant and ultimately, the intellectually lazy. When we really understand the physics and chemistry, the most amazing patterns and stable forms arise, spontaneously and naturally. That's what my entire work is about. It is to remove the superficially mysterious to get at the really deep mystery of life, the universe, and everything. Maybe we shall never arrive at the ultimate mystery, but it is a life-long love affair I have with nature, so I shall never give up trying.

You venture into discussions of more philosophical concepts in your books, including the nature and evolution of consciousness. You include a chapter on time and free will in *RAW*, adopting a Bergsonian and Whiteheadian view of time as pure duration, and suggesting that time is actually quantized rather than continuous, as is matter and energy. Could you describe a little further how you conceive of quantized time and its place in your ideas on consciousness?

The quantization of time that I envisage goes way beyond the usual quantization of action in Planck's constant, and is a speculative idea in thinking of space-time as fractal, as consistent with the fact that different actions have discretely different characteristic time (and space); and the idea that organic processes create space-time. It is also consistent with the finding that living processes and structures as well as non-living processes are indeed fractal, as mathematician Ian Stewart has shown.

Fractal dynamics characterizes intracellular structure, and is the organizing principle in ecology as shown by Geoffrey West and others. French astrophysicist Lauren Nottale has presented a convincing case that the universe itself is fractal. Thus, we have fractal space-time structures on all scales from the universe to the smallest cell and perhaps even fundamental particles.

From the perspective of the entire universe, its duration (present) is still on-going; whereas galaxies have been formed; stars have come and gone; numerous species have originated and become extinct; and astronomical numbers of individual organisms have lived and perished.

Regarding Walter Freeman's work, isn't it a big step to go from transfer of information that is too fast for traditional electrochemical pathways to an assumption that such transfers must be either instantaneous or faster than light? Isn't there a vast middle ground that should be explored first?

The big difference is between conventional explanations based on "electrochemical pathways"—presumably neurons and nerve fibres—and electrodynamical fields. Field effects do not require 'instantaneous' intercommunication, but they certainly act much faster than conduction via nerves and synapses. The point is that quantum coherence automatically includes field effects and beyond.

You suggest that time has a fractal nature. With respect to human consciousness, how does this fractal nature of time manifest itself? Is it amenable to scientific investigation?

Natural processes are fractal. Since the publication of the first edition of *RAW* in 1992, this is now widely accepted. Processes are fractal because they have characteristic time scales, i.e., natural process time is fractal. The fractal nature of organic time is what Bergson meant by 'duration', which one can experience by introspection. In neuroscience, for example, the duration of conscious perception is about 0.5 seconds. Within that duration is a cascade of nested processes each with its own characteristic timescale, and they bear a fractal relationship to one another. In my book, I gave the example of the healthy heartbeat, which has fractal and multi-fractal structure, i.e., self-similarity on many scales. That is the basis for diagnosis of dynamic diseases, which involves a loss of this coherent fractal structure.

Last, what is, in your view, the role of consciousness in the evolution of life, and where are we likely to go as a species in terms of the ongoing evolution of our consciousness?

Consciousness involves a perception of "I", despite the multiplicity of cells and molecules making up our body. In other words, it requires quantum coherence. That was clear to Erwin Schrödinger, and I am happy to follow in his footsteps. In my article "Quantum Coherence and Conscious Experience," published more than 15 years ago, I showed why quantum coherence is a prerequisite for conscious experience. It is interesting to note that Whitehead, who argued that the universe is an organism, containing subordinate organisms all the way down to fundamental particles, endowed even electrons with a kind of primal perception which he referred to as "prehensive unification". More importantly, because we are conscious we can shape and create reality, being entangled with all there is. That is what I regard as the biology of free will. Neither determinism nor randomness rules, only the most sensitive and informed action. Informed actions are those that are maximally coherent with the universe, when we, the knower, are most ourselves and the known universe is most itself. In a Whiteheadian universe, all organisms, including the fundamental particles, are involved in co-creating the universal future, and I am quite comfortable with that view.